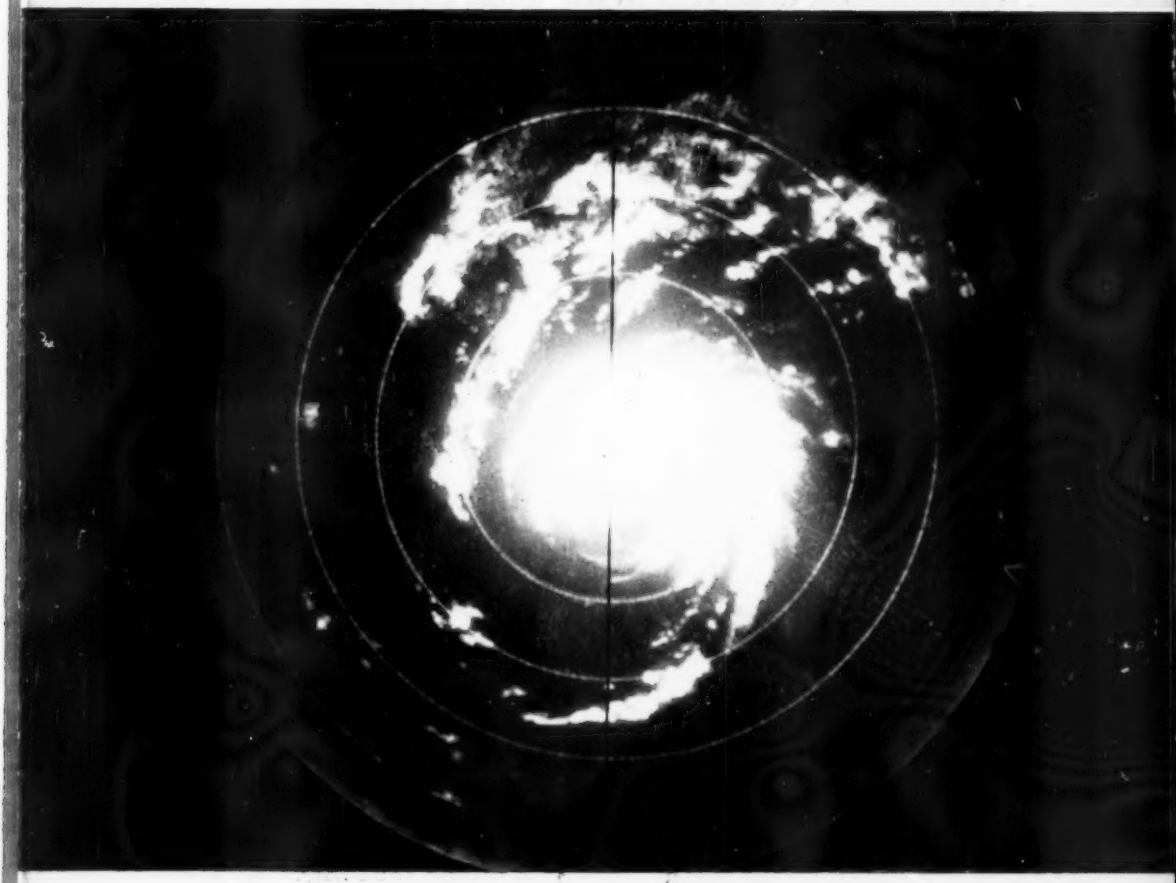
Weatherwise



The Role of the Atmosphere in the Hydrologic Cycle

The Substation Observer and Flood Forecasting

The Hydrologic Services of the Weather Bureau

The Amazing Mr. Buzz

Vol. 2, No. 5, October, 1949

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE" — BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

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THE LATE AUGUST HURRICANE

"IN A CATEGORY just under the great hurricanes of Florida history," is where Grady Norton, USWB hurricane expert at Miami, places the storm that swept over the lower east coast of Florida on August 26th, following a course very similar to that of the great Okeechobee storm of 1928. It passed northward over the Atlantic states and across the northern tip of Maine on the evening of August 29th. It had steadily lost intensity throughout this journey but remained, nevertheless, an exceptionally severe storm.

It was first discovered in the formative stage on August 23rd about 125 miles northeast of St. Martin, Leeward Islands. The accompanying chart shows its course and the maximum wind velocities at various stations in the Florida area. The eye first crossed the Florida shore at Del Ray about 6:00 p.m. on the 26th. Dead calm prevailed at West Palm Beach Airport from 7:20 to 7:42, at which time the lowest sea-level pressure during the storm's course was observed: 28.17 inches. Wind instruments were carried away at 6:03 by sustained 110-mile northeast wind with gusts of 125 m.p.h.

The highest velocity actually recorded in the storm was northeast 153 m.p.h. at Jupiter lighthouse (north of Palm Beach), at which speed the anemometer failed, but the observer reported still stronger gusts after that. In Palm Beach, a privately owned anemometer gave top gusts of 155 m.p.h. (instrument accuracy unchecked). Water piled up 12 feet on the southeast side of Lake Okeechobee, but the dikes held. The heaviest rains were 9.51 inches at St. Lucie Lock (near Stuart), 8.18 inches at Belle Glade, and 7.63 inches at Melbourne.

Losses to all crops, including 14 million boxes

(Continued on page 100)

Chart by U. S. Weather Bureau.

Vol. 2, No. 5 October, 1949

CONTENTS

The Role of the Atmosphere in the Hydrologic Cycle—George S. Benton .. 99
The Substation Observer and Flood Forecasting 104
The Hydrologic Services of the Weather Bureau—Ray K. Kingsley, Jr. 105
Forecasting the Weather — The Weather Types of North America — 5 —Robert D. Elliott 110
The Amazing Mr. Buzz 115
551.5 116
Workshop for Weathermen — Charles A. Laird 118

Cover: A radar photograph of the hurricane in Florida on September 21, 1948, at 10:00 a.m. The periphery gives the directions, with the meridian of the Naval Air Station at Key West, Florida, shown by the line through the center. The circles are believed to be at intervals of 20 miles. See the article, "Hurricane Detection by Radar," by Dr. Harry Wexler, **Weatherwise**, August, 1948, page 78; also October, 1948, page 94. Photograph by the Department of the Navy.

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The devastation that was part of Vanport, Oregon, after the Columbia River dike broke in June, 1948, and flooded the entire city. American Red Cross photograph by Goldsmith.

The Role of the Atmosphere in the Hydrologic Cycle

GEORGE S. BENTON, CIVIL ENGINEERING DEPARTMENT
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DUE TO THE IMPORTANCE of water to human civilization, the occurrence and movement of water in its various forms has been the subject of speculation and investigation since earliest times. Many centuries before Christ it was realized that some sort of a cycle must exist whereby water moved from the oceans to the continents and then back to the oceans again. However, from the beginnings of recorded history to the present day, the importance of the atmosphere in the hydrologic cycle has been consistently underestimated by philosophers, engineers, and scientists. Knowledge of the function of the atmosphere in the water cycle has always lagged behind other phases of hydrologic investigation. Mankind has been unable to appreciate the extreme mobility of the atmosphere and the tremendous quantity of oceanic water vapor which it carries to the interiors of the continents.

Until the latter part of the 17th century, the atmosphere was generally thought to be of secondary significance in the hydrologic cycle. It was believed that the volume of water precipitated on the earth was far too small to account for the observed flow of streams. In addition, it was thought that precipitation penetrated only the uppermost layers of the ground and could therefore not be the source of springs which fed the rivers in time of drought. Both of these erroneous views had been accepted for centuries. Aristotle (384-322 B.C.) wrote: "The water coming out of the earth unites with the rain water to produce rivers. The rainfall alone is quite

insufficient to supply the rivers of the world with water." The Roman philosopher Seneca (4 B. C. - 65 A. D.) declared: "Rainfall cannot possibly be the source of springs because it penetrates only a few feet into the Earth whereas springs are fed from deep down.... As a diligent digger among my vines I can affirm my observation that no rain is ever so heavy as to wet the ground to a depth of more than ten feet."

Many interesting theories were advanced to explain the flow of rivers. Plato (427-347 B.C.) believed that water from the oceans moved under the continents in subterranean channels and eventually reached the surface of the earth as springs. This view was widely accepted, and it was advocated in a somewhat modified form by such eminent scientists and philosophers as Kepler (1571-1630) and Descartes (1596-1650). The latter believed that the subterranean ocean water was evaporated by the heat of the earth, and that the vapor was condensed at higher levels, eventually to flow out upon the continents through springs.

One of the earliest recorded statements of the true role of precipitation in the hydrologic cycle was made by Leonardo da Vinci (1452-1519), who suggested that precipitation was the sole source of surface runoff. However, it was not until the first scientific studies of the hydrologic cycle in the latter part of the 17th century that this view gained substantial favor. Credit for these studies goes to three scientists: Perrault, Halley, and Mariotte. Perrault estimated the precipitation and runoff from the watershed of the Seine River above a point in Burgundy, and showed that the quantity of water which fell on the watershed as precipitation was actually many times larger than the surface runoff from the area. Halley made crude measurements of evaporation, and showed that evaporation from the oceans is more than adequate to account for water supplied to streams. Mariotte verified Perrault's results for the watershed of the Seine above Paris. He also demonstrated that precipitation infiltrates into the ground to great depths and that springs generally increase their flow in rainy weather and diminish in times of drought. These investigations clarified the most important fact concerning the role of the atmosphere in the hydrologic cycle: namely, that the return flow of water to the continents occurs through the atmosphere. Despite the conclusive character of the evidence, however, the new theories were only gradually accepted, and the ancient hypothesis of an underground return of water to the continents was not entirely abandoned until the 19th century.

With the rapid growth of modern science in the 18th, 19th, and early 20th centuries, knowledge of many phases of the hydrologic cycle developed at an accelerating rate. Prob-

THE LATE AUGUST HURRICANE

(Continued from page 98)

of citrus fruits, were estimated at 20 million dollars, property damage at 25 million, all in Florida. In the Piedmont section of the Carolinas the storm was very damaging, spawning four or more tornadoes in North Carolina and a final one at Tidewater, Virginia. Even in upstate New York and New England the storm remained destructive, breaking the long drought.

Excellent Weather Bureau warnings for this storm kept loss of life down to a mere two persons, both of whom failed to heed advices. While the total monetary loss of over 52 million dollars in four southern states was huge, it was probably a minimum to be expected from such a violent natural phenomenon.

This was the second hurricane of the current season to affect the continental United States. The first was charted over the Atlantic on August 21st, but skirted Cape Lookout and Cape Hatteras and turned out to sea, as the accompanying chart shows. D. C. C.

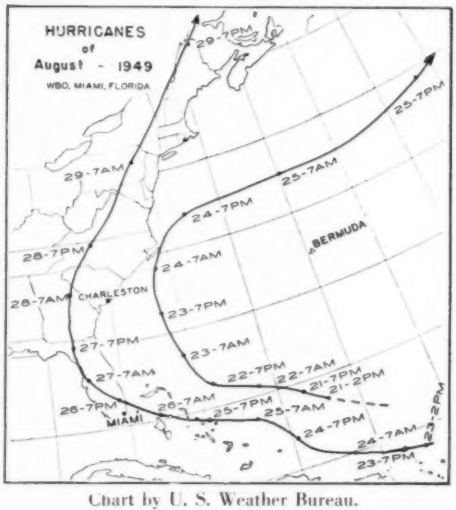


Chart by U. S. Weather Bureau.

lems of infiltration and surface runoff, of soil water and ground water movements, and of evaporation and transpiration were investigated carefully. Nevertheless, the role of the atmosphere in the hydrologic cycle remained comparatively unknown. Beyond the fact that precipitation was the ultimate source of all fresh continental water, little or nothing was known regarding the large-scale patterns of atmospheric movement of water vapor. Undoubtedly, the basic reason for this was the lack of upper-air wind and humidity data, which, together with the lack of a qualitative understanding of the manner in which the atmosphere itself functions, led to the unfortunate development of significant misconceptions concerning the basic character of the hydrologic cycle.

During the last century, the hypothesis was advanced that the greater part of the moisture which was precipitated over the continents was water which had previously been acquired by the atmosphere by the processes of land evaporation and transpiration. This view of the hydrologic cycle minimized the flux of water in the atmosphere from the oceans and essentially equated such flow to the water lost by the continents as surface runoff and subsurface seepage. Little or no important evidence was advanced to substantiate this theory, which was based upon the age-old inclination to underestimate the mobility of the atmosphere and its tremendous power to transport water in vapor form. The theory of a land-derived source of precipitation was advocated during the 19th century by prominent climatologists and hydrologists; it is also firmly established in recent literature. Thus, in 1934, the National Resources Board reported:

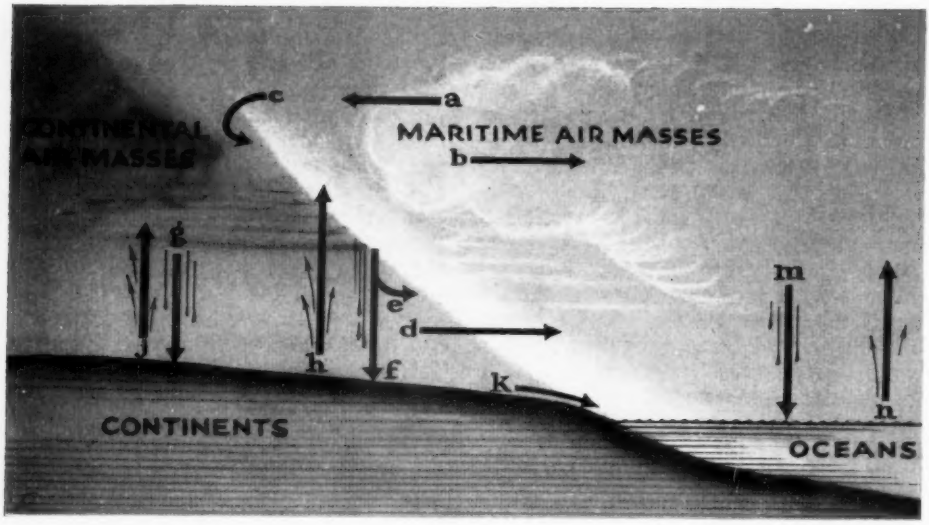
> A considerable portion of the precipitation over any region is derived from local evaporation from that region. Only that part of the precipitation reflected as runoff in streams of the region draining into the ocean is derived from ocean sources.

Or, to take another example, an eminent American hydrologist wrote in 1943 that "little or no vapor of truly oceanic origin may ever reach small tributary areas at the headwaters of large rivers."

The acceptance of this point of view had numerous consequences. Several meteorologists and hydrologists suggested the land source of precipitation as an explanation of the observed tendency of rainy days to follow rainy days and dry days to follow dry days. For, according to this view, increased precipitation would naturally follow increased evapo-transpiration, and the processes of precipitation, evapo-transpiration, and re-precipitation would become a "chain reaction" which would continue until surface runoff depleted the supply of available water. During the droughts of the 1930's, proposals were advanced for increasing precipitation over wide areas by stimulating evaporation and transpiration at the expense of runoff. This would certainly be an important and useful technique, if the basic assumption on which the proposal was based were justified.

The theory of land-derived precipitation was first attacked by Holzman in an excellent paper published in 1937. Holzman based his study on newly available upper-air wind and humidity data and advanced the hypothesis that essentially all precipitation is derived from oceanic water vapor. He maintained that precipitation occurs from maritime air masses; that evapo-transpiration occurs into continental air masses; and that since the air masses are distinct, there can therefore be no important physical connection between the processes of evapo-transpiration and precipitation. Nevertheless, Holzman was unable to advance conclusive proof of these statements. Although he utilized upper-air data to demonstrate that maritime air moving over a continent suffers a net loss of moisture content, he did not show that essentially all precipitation occurred from maritime air. Similarly, although he demonstrated that continental air gains in water content as it moves from its source region over external continental areas, he did not show that essentially all evaporation occurs into continental air masses. His argument that there could be no important physical connection between evapo-transpiration and precipitation was therefore weakened.

Although the theory of an oceanic source for precipitation has been widely accepted by meteorologists as a result of their familiarity with the scale of atmospheric motions, the lack of adequate proof of this hypothesis prevented many hydrologists from rejecting the older beliefs. Indeed, some attempts are still made to defend the theory of a land-derived



The relationship between the hydrologic and air-mass cycles. Drawing by Eric Sloane, after the author.

source of precipitation. However, these attempts are uniformly based either upon speculation or upon erroneous hypotheses concerning the functioning of the atmosphere.

It will be constructive to summarize at this time what modern meteorologists do know about the role of the atmosphere in the hydrologic cycle. It is clear that a close relationship exists between the hydrologic cycle and the air-mass cycle. This relationship is shown here diagrammatically. Maritime air masses moving over the continents result in the influx of a tremendous quantity of water in vapor form (arrow labelled *a*). To this amount is added water which is evaporated or transpired from land surfaces (*h*). The sum of these two must be balanced by loss of water either by return over the oceans (*b*); by precipitation from the maritime air (*f*); or by transfer of water from maritime to continental air masses (*c* and *e*). The latter transfer can be effected in several ways. Part of the maritime air remains over the continents and is modified to form continental air. The fact that the air which undergoes this transition includes a certain amount of moisture enables fresh continental air to have a certain initial moisture charge in its source region. The transfer of water from maritime to continental air represented by this process is indicated in the diagram by the arrow labelled *c*. Other ways in which continental air can gain water from maritime air are by mixing across the frontal surfaces separating the air masses, and by the evaporation of precipitation falling from a maritime air mass through an underlying continental air mass. The net transfer of water from maritime to continental air due to mixing or to evaporation of falling precipitation is shown by the arrow labelled *e*. Considering the processes as a group, we have the relationship that over a long period of time:

$$a + h = b + c + e + f.$$

A similar balance may be set up for continental air. To the initial moisture charge of the continental air (*c*) is added moisture from maritime air (*e*) and moisture from evaporation and transpiration from land surfaces (*j*). This total amount of water must be equal on the average to moisture losses due to precipitation from the continental air (*g*) and to a net transport of moisture from the continent by the continental air (*d*). Thus, we may also write:

$$c + e + j = g + d.$$

In order to complete the picture of the hydrologic cycle, arrows have been entered representing runoff from the continents, and

precipitation and evaporation over the oceans. For the continents, precipitation must balance runoff and evapo-transpiration, and hence:

$$f + g = h + j + k.$$

For the oceans, precipitation plus runoff from land areas must balance evaporation, and hence:

$$k + m = n.$$

On the basis of measurements of precipitation and runoff from land areas, it is possible to assign relative weights to certain of the above rates of moisture transport. Thus if total precipitation over continental areas is 100 units ($f + g = 100$), the runoff from the continents to the oceans is approximately 30 units ($k = 30$), and total continental evaporation and transpiration will be approximately 70 units ($h + j = 70$). From this it can also be deduced that oceanic evaporation must exceed oceanic precipitation by 30 units ($30 + m = n$). Furthermore, Holzman's work has shown that precipitation from maritime air exceeds evapo-transpiration into maritime air ($f > h$), and that evapo-transpiration into continental air exceeds precipitation from continental air ($j > g$). Nevertheless, it is indicative of our lack of knowledge of the role of the atmosphere in the hydrologic cycle that, with the exception of runoff (k), measurements of none of the individual rates of moisture transport in the diagram have been made. Even careful estimates of the comparative magnitude of most of these quantities are not available in the literature.

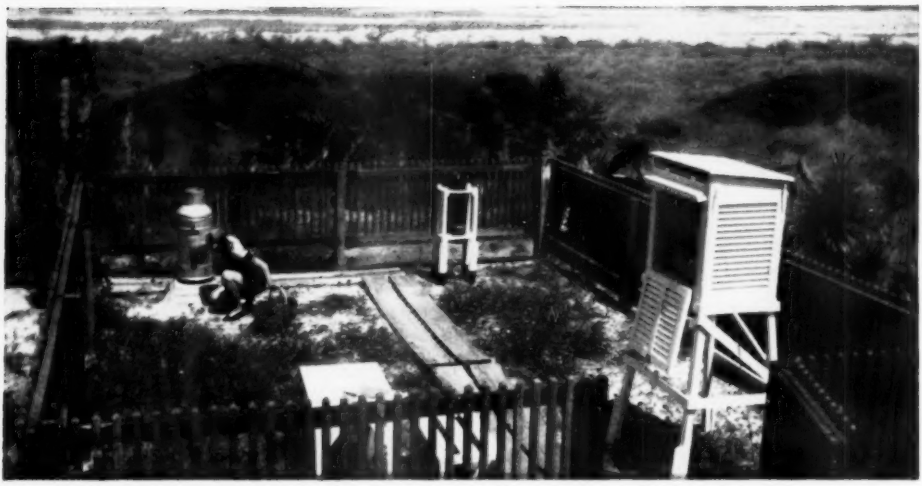
In a recent study,[1] however, the present author in collaboration with R. T. Blackburn and V. O. Snead has utilized a slightly modified diagram in making a careful analysis of the hydrologic balance of the Mississippi watershed. In this study, the individual rates of moisture flux have been estimated for the first time. The results have served not only to clarify the relationship between the hydrologic cycle and the air-mass cycle, but also to present estimates of the percentage of precipitation over the Mississippi watershed which is land-derived in origin. As most meteorologists would anticipate, the results largely confirm the hypothesis advanced by Holzman: most of the precipitation has oceanic water vapor as its direct source; only a small percentage can be traced to land evapo-transpiration. Not more than 10 per cent of the precipitation within the Mississippi Valley can be traced to evapo-transpiration from within the valley, and probably not more than 12 to 14 per cent can be traced to land evapo-transpiration from any source, either internal or external to the watershed.

The consequences of this fact are clear. Since such a low proportion of the total precipitation is land-derived, even for such a large watershed, it must follow that increases in evapo-transpiration due to changes in land use will have only a small effect on precipitation. Although the amount of precipitation will vary from year to year and century to century, these variations will primarily be a function of such variables as the intensity of hemispheric circulations. Precipitation is not, and cannot be, a "chain reaction."

Nevertheless, the percentage of precipitation that is land-derived is large enough to warrant a word of caution. If as much as 12 or 14 per cent of the total precipitation over the Mississippi watershed is land-derived, then possibly as much as 20 or 30 per cent of the precipitation over a local area may be traced to land sources. For example, it is possible that evapo-transpiration into maritime tropical air in the southern part of the United States may add measurably to precipitation in Minnesota or North Dakota. Whether or not this is actually the case can only be determined by further study. Nevertheless, even if true, this relationship could hardly be of economic significance. Due to the extreme mobility of the atmosphere, the land sources for precipitation in one region are bound to be hundreds or even thousands of miles away from that region. Increasing or decreasing precipitation even slightly by local regulation of land use is therefore out of the question.

Unquestionably, the hydrometeorologist of today has a considerable task ahead of him. Mass movements of water vapor in the atmosphere must be charted in all parts of the world. The study of the role of the atmosphere in the hydrologic cycle has lagged far behind the study of other phases of the cycle. By utilizing and improving the measurements of upper-air conditions this deficiency can and will be remedied.

[1]To be published in the *Transactions* of the American Geophysical Union.



Co-operative observer, Mrs. T. B. Gillespie, of St. Augustine Beach, Florida, is reading the chart of her recording rain gage. Also shown are the standard Weather Bureau thermometer shelter and rain gage. Mrs. Gillespie is a member of the Amateur Weathermen of America.

The Substation Observer and Flood Forecasting

THE TWO ESSENTIALS of a flood forecasting program are data and methods. Without forecasting methods, it is almost impossible to interpret the data and translate into accurate stage forecasts. On the other hand, basic facts are vital in the development of these methods, and without current reports of rainfall, river stage, snow, and the like, the best forecasting method is useless.

The substation observer thus plays an important role in the success of the Weather Bureau's flood forecasting service. From the network of climatological stations manned by unpaid co-operative observers comes information which is needed in the preparation of the many curves and charts required to formulate forecasts. From among this same group of observers many are selected as reporting observers. The stations are selected from those that are most useful in the development of procedures.

Reporting observers operate under instructions which vary somewhat from area to area depending on the river problems. Generally, however, they are instructed to wire or telephone a report to the Weather Bureau River District Office whenever one-half inch or more of rain is observed at 7 a.m. and to continue reports every six hours until the rain ends. They also mail a postcard report each time rain is measured at the regular observation time. River observers usually report every day that the river is above an established critical stage at their station.

Reporting observers are generally paid either a small fee for each report or a small monthly wage. Available funds are so limited that these observers' wages are more a token payment, and do not represent a true compensation for services rendered. Some observers in remote locations must go long distances to read their river gage or to reach a telephone from which to file a report. They are sometimes called out of bed in the middle of the night to read their gages, and in a real emergency some have been asked to report every hour or two, day and night. The storms that cause floods often disrupt communications, and the observer may have to get his report through by amateur or police radio or other emergency means.

The Weather Bureau has always felt that the real incentive to such observers is not the meager wage but rather the sense of a public service well done. They know that their reports are vital if warnings are to be issued in time to prevent loss of life and property along our streams.

The Hydrologic Services of the Weather Bureau

RAY K. LINSLEY, JR., ASSISTANT CHIEF FOR HYDROLOGY
DIVISION OF CLIMATOLOGICAL AND HYDROLOGIC SERVICES, U. S. WEATHER BUREAU

HYDROLOGY, the science which deals with the occurrence and behavior of water on the earth, is necessarily closely related to meteorology, since weather events such as snow and rain directly affect the flow of streams. It is not surprising, therefore, that the Signal Corps of the Army in the 1870's and 1880's undertook in a limited way to forecast floods as well as weather, nor that, when the Weather Bureau was established, in 1891, Congress gave it basic authority to "gage and report the rivers." Since the creation of the Weather Bureau, its River and Flood Forecasting Service has been an important, though perhaps little known, phase of its activities.

Beginning on the Potomac, Savannah, and Lower Mississippi rivers, service was gradually expanded until almost the entire country is included in the 85 river districts now active (Fig. 1). A history of the early activities of the service would make interesting reading. Limited by a very restricted understanding of the phenomena of floods, hampered by inadequate communications and small appropriations, the service early established a high reputation for accuracy. In the flood of 1894 the Portland, Oregon, station was credited with saving over $200,000 worth of property in that city alone. In 1895, the forecaster at Cairo, Illinois, devised the scheme of posting forecasts and warnings on a large bulletin on a river steamer so that all interests could be informed of the situation.

For many years the general plan of operation of the River and Flood Forecasting Service was not changed, although the service was gradually expanded and techniques steadily improved. In the early 1930's the federal government embarked on an extensive program of flood control, soil conservation, hydroelectric power development and other

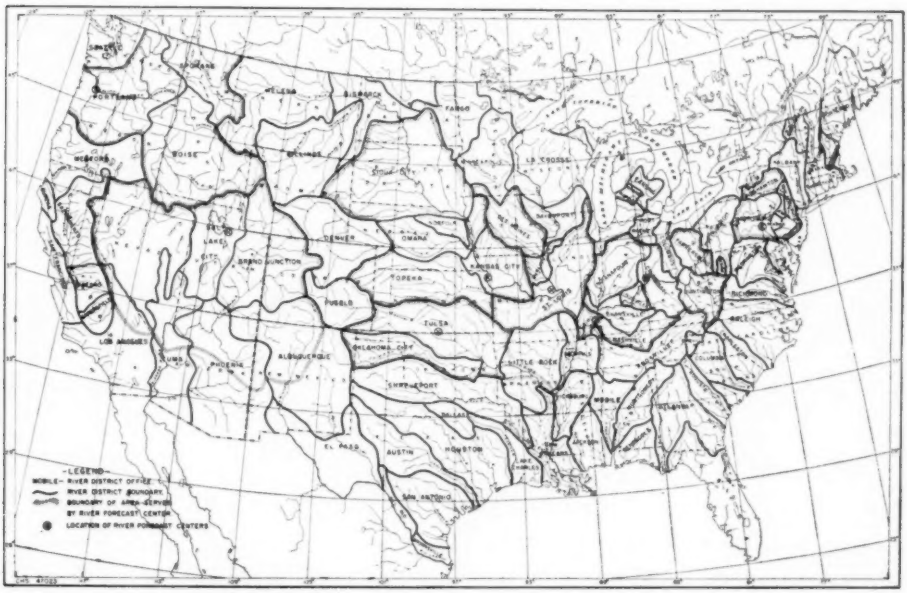


Fig. 1. The distribution of the 85 river districts now active in the River and Flood Forecasting Service of the Weather Bureau.

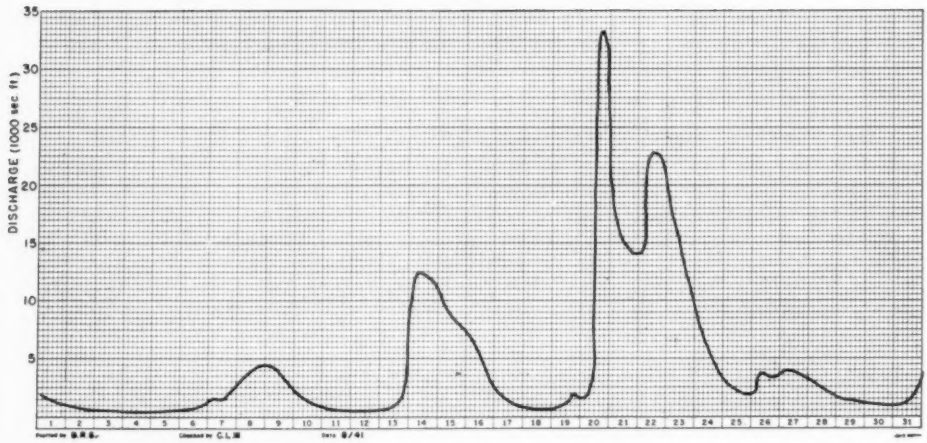


Fig. 2. A hydrograph plot for the Cottonwood River at Cottonwood Falls, Kansas. The material was compiled for the month of October, 1941, at the Kansas City river forecast center.

water control work. Hydrology, which had hitherto been largely a descriptive science, received a tremendous impetus and many research projects were inaugurated in an effort to develop the quantitative phases of the science. Techniques and procedures were rapidly developed, and in 1937 the Weather Bureau began employing hydraulic engineers to bring to the river and flood program the scientific aspects of hydrology.

New forecasting procedures were soon placed in operation in the Susquehanna and Potomac River basins, and assistance was given to many other river districts. However, the first major addition to the program was made in 1945, when a program of quantitative water supply forecasting for the western states was initiated. This was followed in 1947 by the establishment of river forecast centers at Cincinnati and Kansas City, and in the following year similar centers were established at St. Louis, Tulsa, and Harrisburg. Also, the water supply forecast work formerly conducted from Washington was turned over to centers at Salt Lake City and Portland, Oregon. The establishment of these centers marked the first real change in program since the beginning of the service. Trained hydrologists with modern techniques were available to make forecasts undisturbed by the tremendous pressure of telephone inquiries and press deadlines under which the river district officials were obliged to work. Relieved of the responsibility for preparing the forecasts, the local official can devote his efforts to interpretation and dissemination of river forecasts exactly as he does for weather forecasts, secure in the knowledge that the forecasts are as accurate and timely as modern hydrology will permit. It is hoped that similar forecast centers can soon be established to serve the rest of the country.

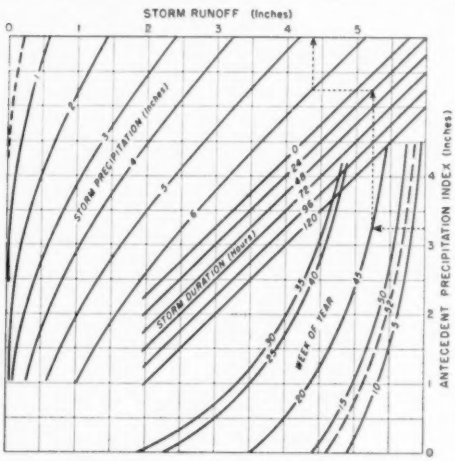


Fig. 3. The runoff relation for the Monocacy River at Jug Bridge, Maryland, with curve-families superimposed. In the example shown by the arrows, a runoff of about 4½ inches is indicated.

How Flood Forecasts Are Made

The cause of nearly all floods is heavy rain, and hence a network of reporting rain-

fall stations constitutes the first essential of a flood forecasting service. The observers are paid a small fee, either on a monthly wage or a "per-call" basis. Their reports are transmitted by phone or telegraph to the river district office representing the area. In addition to rainfall reports, messages indicating river stages at key points along the streams are also received.

The reports assembled at the river district office are transmitted as a combined message via TWX connections to the river forecast center. As the data come off the TWX machines, they undergo a detailed and thorough analysis. The entire technique of analysis and forecasting is carefully planned in advance, and all employees are so thoroughly trained that the procedure may be accomplished in a minimum of time with no chance for errors or omissions. Precipitation data are plotted on base maps so that the forecaster may determine the average over particular tributary basins. River stages are converted to discharge and plotted on continuous hydrographs (Fig. 2). Hourly airway weather reports are analyzed to determine the time during which precipitation occurred, and a weighted value of precipitation over a 30-day period prior to the storm is computed.

The forecaster is then ready to predict the amount of rainfall which will run off the land and enter the stream. For this he uses a relation developed by graphical analysis of storms during the past 10 years of record (Fig. 3). Entering with the known data for the current storm and following the arrows, he computes that 4.5 inches depth of runoff will occur. He then turns to a tool called the unit hydrograph (Fig. 4). These graphs tell him what the shape of the runoff hydrograph will be for any given duration of rainfall and pattern of rainfall distribution. Selecting the proper graph for the existing conditions, he multiplies the ordinates by 4.5 (the estimated runoff) and adds this to the flows which would have occurred had there been no rain. The result is a predicted hydrograph for a particular river station from which the river height may be determined for any specific time. A similar process must be followed to prepare a forecast for each headwater station.

On very small streams the flood crest may

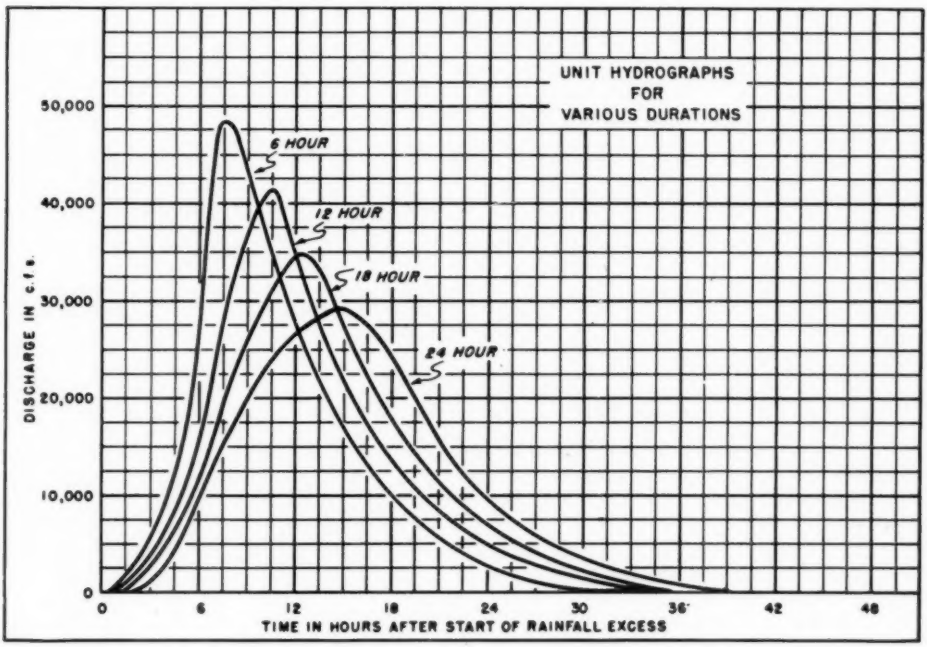


Fig. 4. A unit hydrograph chart, with the discharge indicated for the duration of rainfall.

come so soon after the end of rain that it is not possible to collect the data, determine the forecast, and relay it to the public in time. The forecaster then reverses his procedure, and when rain is expected computes how much rain will be needed to raise the river to flood stage. This report is transmitted to a responsible public official in the community, who, on the basis of rainfall reports, can anticipate flooding and warn the local residents.

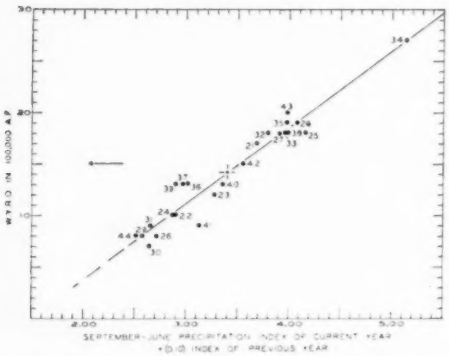


Fig. 5. An approximate linear relation is obtained from the 1921 through 1944 average of precipitation and water-year runoff, and may be used as the basis of predicting runoff from the current-year precipitation index. Data for Coeur d'Alene River near Cataldo, Idaho.

The flood forecaster's work does not end with the headwater basin. He must forecast stages and flows at downstream stations. This means that he must combine the forecasts for two or more tributaries and move progressively downstream. As the flood wave moves down the river, a portion of the water during the rising stage is required to fill the channel, and is not released until the stream begins to fall. The forecaster takes this channel storage into account by a process called "routing," using a graphical relation determined by analysis of past floods. Recently, Weather Bureau hydrologists and instrument technicians have perfected an electronic circuit which will solve routing problems more rapidly and more accurately than present manual methods.

Water Supply Forecasting

In the western states large quantities of water accumulate as snow in the mountains. This natural reservoir surpasses the capacity of all the man-made reservoirs in this country. The stored water is released by melting during the late spring and summer at the time it is most needed for irrigation. This lag between precipitation in the form of snow and its runoff into the streams makes possible long-range forecasts of water supply.

The basic principles are the same as those for flood forecasting, but the specific techniques are vastly different. The forecasting relation is developed by the statistical analysis of long records of precipitation and stream flow. The basic data must first be adjusted to correct for any changes brought about by changes in measurement techniques or movement in the location of stations. Relative weight, determined statistically, is then given each precipitation station. In a like manner, the relative importance of each month from September through June is determined, and finally the contribution of the previous year to ground water carryover is established.

The actual preparation of the forecasts is relatively simple. As the monthly reports of precipitation are received from co-operative stations, the forecaster enters these amounts on his computation form. Each station amount is properly weighted, the total weighted for the month, and the contribution of the previous year added. The forecast of stream flow can then be read from the curve (Fig. 5).

It is obvious that on January 1st much of the precipitation for the season has not yet occurred, and hence a forecast in final terms cannot be made. In lieu of a specific estimate, the Weather Bureau forecasts give five possible values, assuming that the precipitation yet to come may equal the median, quartiles, or extremes of the record. The odds for each forecasting value being known, the operator may select that which must control his operations. Each month the percentage of observed data increases and the range between the five estimates decreases (Fig. 6), until on April 1st the limits are so close that the irrigator or power engineer is in a position to adjust the remainder of the operating season to the forecast having the best chances of verification. In utilizing the forecasts, the operator is in a position to make substantial savings in planning purchase of seed, acreage of land to be planted, and fuel to be purchased to supplement hydroelectric power.

Hydrometeorological Studies

River forecasting is not the sole function of the Hydrologic Service Branch of the Weather Bureau. Hydrology is an important phase in the design and operation of flood control works, water supply systems, irrigation projects, and similar works, and the great mass of meteorological data and knowledge accumulated by the bureau can make important contributions. Hydrometeorological studies are an interesting phase of this co-operation with design agencies. One factor every designer must be concerned with is the safety of his project. Some loss is encountered in the event of failure of almost any structure, and in the case of a large dam failure may result in damages downstream many times the value of the dam itself. Consequently, the designer is entitled to know what the most severe flood conditions might be at the dam, although economic considerations may require that the structure be designed for some lesser flood.

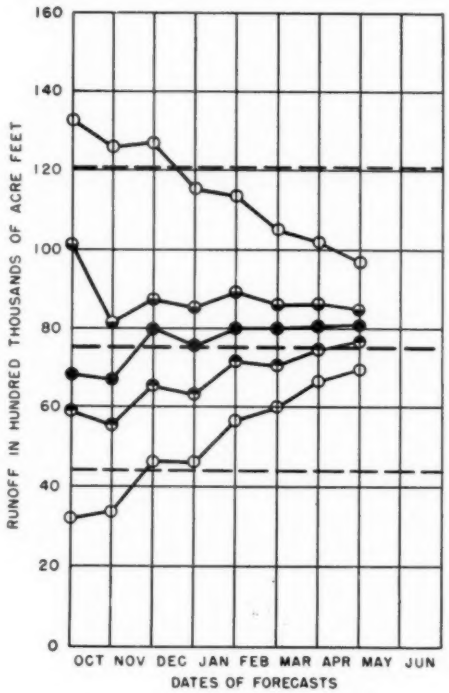


Fig. 6. A sample of a progressive forecast chart, in this case for the Yellowstone River at Miles City, Montana, in 1947-48.

In 1939, a co-operative arrangement was made with the Corps of Engineers, Department of the Army, through which a Hydrometeorological Section was established in the Weather Bureau to make studies of maximum possible storms for various river basins as assigned by the Corps of Engineers. In 1945, a similar section called the Co-operative Studies Section was established to serve the Bureau of Reclamation in a similar manner.

Drawing on a reservoir of carefully analyzed data on over 1,000 major storms prepared by field offices of the engineers, these sections determine for each assigned basin the maximum possible precipitation or combination of precipitation and snow melt that could occur. The result is usually expressed as a family of curves showing average depth of precipitation as a function of area and duration. In addition, these sections serve as consultants to their respective agencies on many other special problems. The Hydrometeorological Section has prepared a detailed report on thunderstorms, and is currently engaged in a study of hurricane winds in Florida. The Co-operative Studies Section has developed a technique for estimating normal annual precipitation on the basis of topographic parameters.

SEPTEMBER SNOWSTORM

A total snowfall at Helena, Montana, of 7.5 inches on September 10-11, this year, was the greatest recorded so early in the season in the 70 years that records have been maintained, according to R. A. Dightman, USWB meteorologist there. The greatest amount of snow on the ground at any one time was 6.2 inches, measured at 11:10 a.m. on the 11th.

In the surrounding area, Bozeman reported 4½ inches of snow, Butte and Anaconda four inches, and smaller amounts occurred over most of the state west of the 109th meridian. The snowstorm was produced by the interaction of a cold polar air mass with a warmer, fairly moist air mass, rain gradually changed to snow.

Temperatures fell rather sharply from the 80's on the 9th until many maximums did not reach 40° on the 11th. Freezing was quite general on the morning of the 12th, and the minimum of 22.2° at Helena was a record so early in the season.

With shade trees in the city still carrying their summer foliage, the snow was sufficient to cause severe damage to a large number of older and larger trees. Traffic was slowed over nearby mountain passes, but no road closures have been reported.

FORECASTING THE WEATHER

The Weather Types of North America — 5

ROBERT D. ELLIOTT
AMERICAN INSTITUTE OF AEROLOGICAL RESEARCH

IT WAS POINTED OUT previously (**Weatherwise,** February, 1949) that there are two type zones for North America, one embracing the sector from 135° west to 90° west and the other covering the North American area to the east of 90° west. The types which have thus far been shown for the eastern zone are merely those which normally follow the respective western zone types. Several different eastern zone types may actually follow from a given western zone type, the weather pattern in the narrow transition area between the two zones depending upon the character of the types involved.

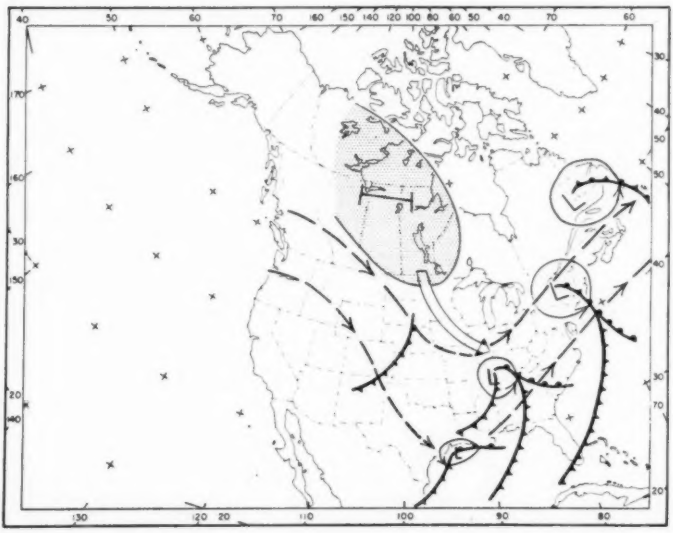
It is a characteristic of the eastern zone that the type moving out of the area may leave behind a trailing frontal zone in the Gulf of Mexico which lingers on until the next type moves in. As the frontal trough of this new type moves eastward it often causes the development of a new low (cyclogenesis) on the Gulf front. The Gulf wave then moves northeastward, thus profoundly affecting the weather pattern in the eastern zone. There are two types of Gulf waves, and they are denoted **Ga** and **Gb.** These will be described below.

As winter yields to spring, there occurs a peculiar shift in the region of cold air-mass genesis to the north. There are fewer and fewer cases of cold air-mass outbreaks having their origin in Alaska and northwest Canada and an increasing number of outbreaks from the Hudson Bay area. It would appear that the cold pole of the Northern Hemisphere shifts eastward, which indeed it does, starting out in northeastern Siberia in winter and shifting over to Greenland by summer.

In the spring and early summer the cold waters of the Hudson Bay warm up much more slowly than the land surfaces in these northern regions, and they therefore act as a cold source, capable of producing and maintaining a high pressure area. On occasion, this high extends well southward into the Middle West and tends to persist in one position for some time. Lows moving in from the west are shunted southward around the high. This type is called **Ha.** On other occasions the high, or a portion of it, moves almost due south along the East Coast and appears to merge with the Bermuda high cell (a western lobe of the subtropical Azores cell). This is called type **Hb.**

During late summer and autumn, hurricanes may be a factor of importance in the Gulf and East Coast regions. The various hurricane tra-

TYPE Ga OF NORTH AMERICAN WEATHER TYPES



jectories have been given different type designations, but these will not be discussed here.

As in the preceding issues, the types are represented by schematic diagrams, each diagram covering the number of days required for one cyclone to advance eastward across North America. The mean upper-level flow for each type is indicated by dashed lines and arrows. Areas of persistent high pressure are delineated by stippling and double arrows indicate trajectories of major polar outbreaks. Successive daily positions of a single cyclone and its associated frontal system are shown in conventional weather map fashion.

TYPE Ga

The upper-level pattern is characterized by a trough in the East which tends to steer the Gulf wave northeastward along its eastern edge. There is usually an upper-level crest located between 110° and 130° west.

At the surface, a frontal remnant from the preceding weather type has lingered in the Gulf of Mexico and, as a frontal trough from a new type advances eastward into the eastern zone, a wave forms on this front. It advances northeastward, passing inland west of New Orleans, then moves up just west of the Appalachians, becoming more intense and active as it moves. Because there is an influx of warm moist tropical Gulf air northeastward, copious precipitation occurs in the Gulf states, the Ohio Valley, the eastern Great Lakes area, and all along the Appalachians. Cold air moves in behind this low, but the excessive warmth preceding the cold front passage is usually of greater extreme than the succeeding cold, and temperatures are above normal from the Mississippi eastward south of the 45th parallel, but near normal or below in the balance of the eastern zone.

This type most often follows the occurrence of western zone types having an upper-level mean crest position between 110° and 130° west, which includes all the **B-north** types. It is most frequently observed in winter and spring.

TYPE Gb

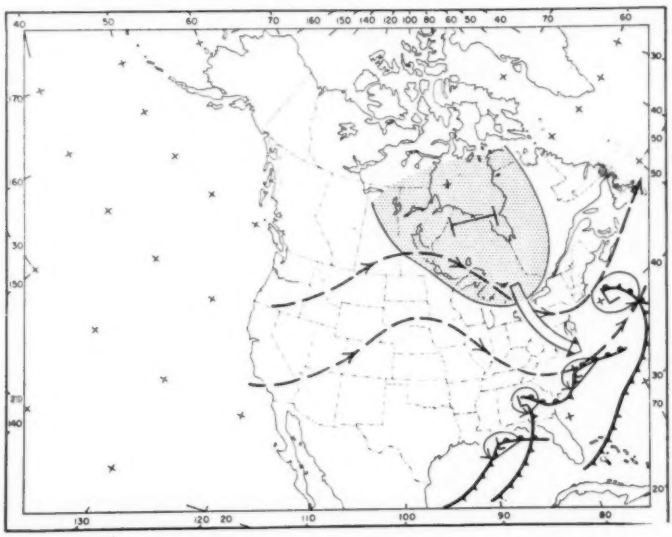
There is present a rather sharp crest aloft near 100° west and a trough along the East Coast. Usually a trough exists also somewhere near or off the West Coast.

At the surface, a frontal remnant from the preceding weather type has lingered in the Gulf of Mexico. The next frontal trough advancing eastward in conjunction with the new type causes a wave to develop on this front. The wave moves east-northeastward, entering the coast east of New Orleans. While it crosses the southern Appalachians, a peculiar thing happens. A new low center forms off the Carolina coast. This immediately becomes the dominant storm and advances northeastward up the East Coast, deepening rapidly as it progresses.

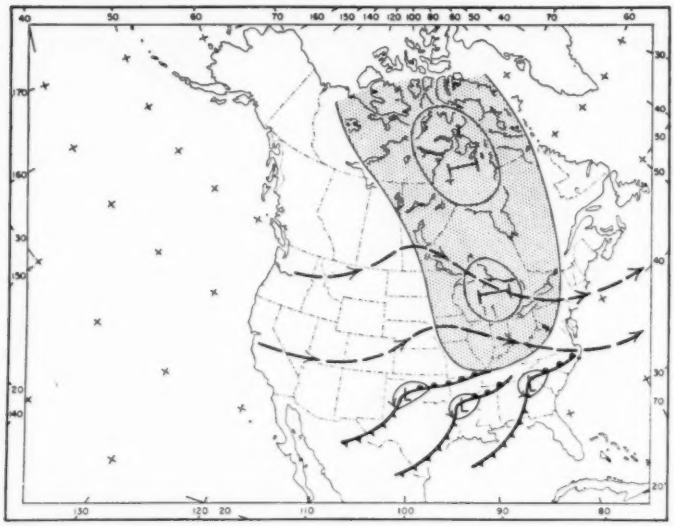
Precipitation is moderate to heavy in Alabama, Georgia, and all along the coast east of the mountains. This type produces New England's "northeasters" and, in winter, accounts for most of the snowstorms which occur from Washington, D.C., southward along the eastern coastal plains. To the north, it may or may not produce heavy snows on the eastern seaboard depending upon the proximity of the Atlantic storm center to the coast.

Because a considerable amount of cold air

TYPE Gb OF NORTH AMERICAN WEATHER TYPES



TYPE Ha OF NORTH AMERICAN WEATHER TYPES



is drawn southward behind the deepening low, temperatures are generally below normal in the eastern zone.

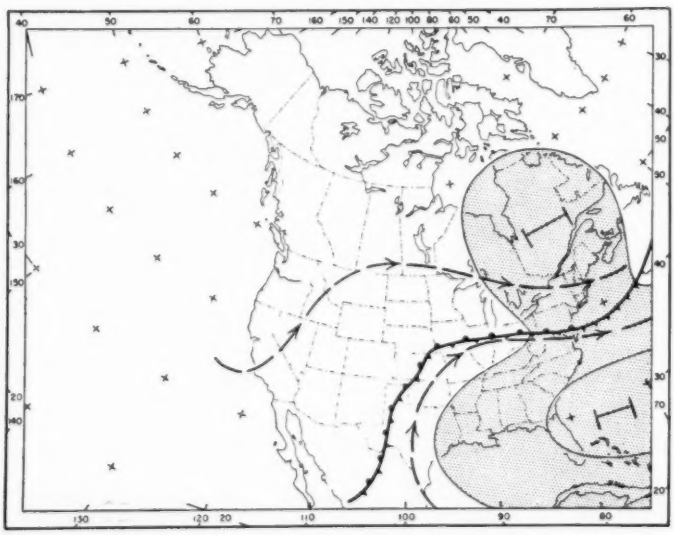
This type most often occurs following an **A** or **D** type in the western zone. It is most frequently experienced in winter.

TYPE Ha

The characteristic features aloft are a slight crest at a mean position of 95° to 100° west. A trough exists along or off the East Coast and there is often a weaker trough in the western zone.

At the surface, an unusually obstructive Hudson Bay high extends southward in the form of a ridge, with a separate high center over the Great Lakes. This high is quite persistent, and lows moving in from the west are deflected

TYPE Hb OF NORTH AMERICAN WEATHER TYPES



southward around it. The eastward progress of a wave is indicated on the diagram, but movements are so erratic with this type that it is difficult to present a meaningful picture.

Precipitation is greatest in the Mississippi Valley and in the Gulf states, with abnormally dry weather in the region dominated by the high.

Temperatures are below normal in the Northeast, elsewhere near or above normal.

This type is most frequently experienced in spring and late winter. It usually occurs in conjunction with the **E** types of the western zone.

TYPE Hb

Aloft there is an anticyclonic flow pattern in the southeast, a flow toward the west in the Gulf of Mexico and the Caribbean, toward the north in the south central states, and toward the east in the northeast states. A trough normally exists along the West Coast.

At the surface, the Bermuda high cell (western lobe of the Azores subtropical high cell) is quite strong and prevents frontal systems from invading the Southeast. It completely dominates the weather in the southeast and Gulf states where hot humid weather is the rule, with thunderstorms along the Gulf Coast, in the lower Mississippi and Ohio valleys, and over the mountains. To the north, over Quebec and Hudson Bay, high pressure prevails with cool relatively dry air at the surface. This cool air pushes southward some distance through New England and the central Atlantic states as depicted in the diagram. The nearly east-west frontal zone separating the cool and warm air masses sometimes advances southward, then recedes northward, as cool and warm air masses battle for position. To the heavily populated districts of the northeast coast, the position of this front may mean the difference between cool sea air and hot humid air. Thunderstorms can be expected right in the frontal zone.

This type occurs almost exclusively in the summer.

ANOTHER "WETTEST SPOT ON EARTH"

A new contender for the dubious title of "the wettest spot on earth" has been brought forward. It is the peak of 5,080-foot high Mt. Waialeale on Kauai, Hawaiian Islands.

An average annual fall of 474.11 inches has been registered there during the past 37 years, and the fall during 1948 amounted to 624 inches, or 52 feet of water.

During the present season a new rain gage is to be delivered to the summit by helicopter since the rain-soaked sides of Waialeale make packing up a heavy rain gage very difficult. The new gage will operate on the siphon principle and thus it will have an unlimited capacity.

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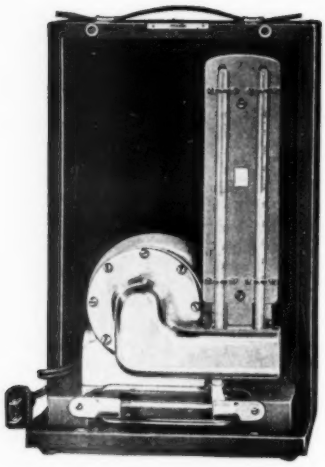

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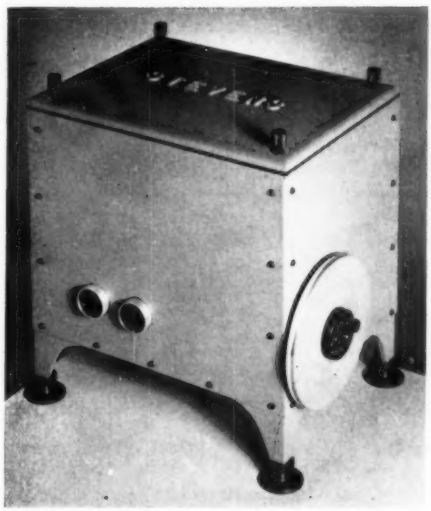
Buzz is a nickname for the Stevens Telemark, an uncanny device for signalling water level readings by telephone. This system played a big part in the accurate forecasting of the great Columbia River flood of 1948, and at the present time the Bonneville Power Authority keeps four cousins of Buzz on duty at all times on the upper reaches of the Columbia basin.

The forecaster at Portland just calls long distance — then writes down the readings transmitted in simple code by the robot reporter, who keeps constant tabs on what the river is doing. The Telemarks of the Bonneville Power Authority are installed in concrete gaging stations of the U. S. Geological Survey, sharing space with graphic water level recorders.

The Telemark is controlled by a float, which rests on the water in the float well. The float pulley, turned by the rising and falling float, governs the positions of the ridged disks inside the Telemark, which may be three or four, depending on the range in stage and whether tenths or hundredths of feet are to be registered. Each instrument used by Bonneville has four disks. When the Telemark is called by telephone, a contact arm begins to revolve, sweeping over the ridged disks, and the instrument buzzes its signal over the telephone.

You may hear, for example, "Buzz, buzz," — two shorts, which you transpose by writing 2.



The Stevens Telemark, known as "Buzz."

After a moment of silence, you hear, "Buzz, buzz, buzz, buzz," and write 4. Another interval of silence. Then a long "Buzz-zz-zz"; you write zero. And, after another pause, "Buzz, buzz," and you jot down 2. Pointing off two decimals, you read the water level: 24.02 feet.

The contact arm makes one complete revolution as it signals the numbers corresponding to the water level. It requires about a minute to complete a signal from a four-disk Telemark.

Buzz also operates in many other parts of the world. He is employed by many city water bureaus and utilities; by the Tennessee Valley Authority; and by the Panama Canal Zone. Even in remote Australia and New Zealand, he performs important duties in reducing property damage and in preventing loss of life.

In this tower (six feet square) at the head of Celilo Falls, Oregon, on the Columbia River, Buzz shares space with a water-stage recorder of the U. S. Geological Survey.

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RECENT LITERATURE ON HYDROLOGY

Elements of Applied Hydrology, Johnstone and Cross (Ronald Press); **Hydrology,** Wisler and Brater (Wiley); **Applied Hydrology,** Linsley, Kohler, and Paulhus (to be released by McGraw-Hill, Oct., 1949); **Rainfall and Runoff,** Edgar E. Foster (Macmillan); **The Hydrologic Handbook,** American Society of Civil Engineers.

TODAY, there exists a working library in hydrology that has no counterpart in the literature of this rapidly developing applied science. For many years there was almost complete dependence on the classical works of Meyer and Meade. Throughout an extended interim of 20 years the journals of technical and scientific societies were the sole media of dissemination, with the exception of the symposium on hydrology, as volume IX of the Physics of the Earth series, National Research Council, edited by the late O. E. Meinzer (see below). Hydrologists will therefore welcome the five recently published books on hydrology now available to them. These works are held together through a mutual dependence on the hydrologic cycle as the basis of contents. There are, however, sufficient deviations in emphasis and in the mode of presentation to insure, among the five, the most comprehensive treatment of modern hydrology, the science having as its base the waters of the earth.

It is to be noted that in all cases the authors are engineers. This has not prevented Foster, and Linsley, Kohler, and Paulhus, from including a comprehensive discussion of meteorology in support of the subsequent phases of the cycle involving runoff, infiltration, and ground water. All seek to serve the engineer-hydrologist who must plan, build, and operate flood control and water utilization projects, and to this end graphical displays and working tables are believed to be adequate. Not content with the theoretical and empirical interpretation of hydrologic data, all of the works reviewed give guidance to the identification of data sources and to data processing. The extent to which

NEW BOOKS RECEIVED

HYDROLOGY. Edited by Oscar E. Meinzer. Dover Publications, Inc., New York, 1949. 714 pages. $4.95.

This is Volume IX in "Physics of the Earth Series" and was originally published in 1942. Twenty-four experts have contributed 15 chapters that occupy 714 pages. Much material is presented here that is not contained in the ordinary meteorological text. Of special interest to practicing weathermen will be the chapters on Evaporation, Snow and Snow Surveying, Glaciers, and Soil Moisture.

bibliography is provided varies rather widely through the series. **The Hydrologic Handbook** will be found to carry references to 21 items of hydrologic literature, many of which are identified in the text as the most appropriate for use by the handbook user.

Perhaps it can be said that the hydrologist has acquired the first foot of his ultimate x-foot book shelf.

MERRILL BERNARD, Chief
Climatological and Hydrologic Services
U. S. Weather Bureau

RADAR AND RAINFALL

G. E. Stout, and **F. A. Huff,** Report of Investigation No. 3, State Water Survey Division, Urbana, Illinois, 1949. 59 pages, 3 appendices.

RADAR, in use for several years to locate and track the movement of rainfall areas, successfully indicated the spatial extent and the relative intensity of precipitation in experimental work carried on by the Illinois State Water Survey Division in co-operation with the Pfister Hybrid Corn Company of El Paso, Illinois. The project was organized for the intensive study of the precipitation pattern in a small area of central Illinois, southeast of Peoria.

From the undertaking, it is planned that practical application of the technique may be developed for precipitation studies on watersheds. Since there is considerable variation in precipitation over short distances in Illinois, the use of the new tool, radar, becomes essential to determine the pattern of distribution, frequency, and intensity of storms.

When are conditions favorable for inducing precipitation by artificial means? Rainfall at a particular observation point might have been induced once every fifth day, based upon the fact that there were about 18 days during June, July, and August, which were favorable for artificial seeding. However, the data only gives an indication that precipitation would be induced. Whether the results would be different under field conditions requires further study and experimentation.

DAVID C. WINSLOW
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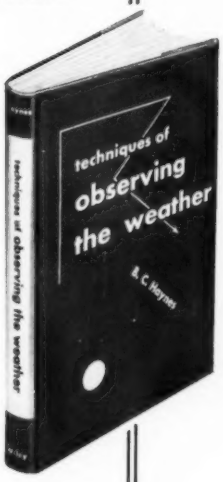

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CONDUCTED BY CHARLES A. LAIRD

How to Construct an Ombroscope

WHAT time did it rain last night? An oft-repeated question, particularly among amateur weathermen.

The apparatus described here, sometimes called an ombroscope, will show the time of beginning and end of rainfall over any 12-hour or 24-hour period. Basically, the instrument consists of a disk about six inches in diameter, rotated by an ordinary clockwork. A disk of paper, of the same diameter as the disk rotated by the clock, is ruled with ordinary indelible pencil or copying ink, as shown in the figure. Covering the rotating disk and paper chart is a "rain shell," which may be made of a common 8-inch pie tin. Or you may construct one of sheet metal.

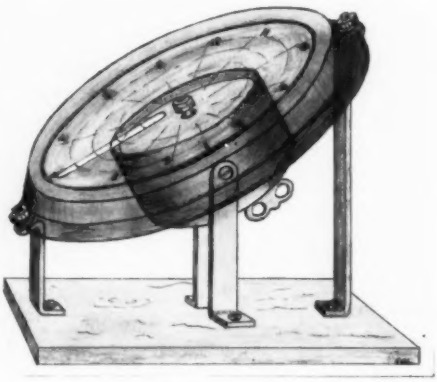
As shown in the phantom drawing, a slit about ⅛-inch wide is cut in the pie tin, radially from near the center toward the outer edge. As the ruled paper chart revolves under this slit, time lines are exposed and any rain falling through the slit will strike the chart and show up there, changing the ruled lines to a brighter color. When the chart is removed, bright-colored lines will show the times of rainfall.

Construction of this apparatus is quite simple. The assembly is mounted on a section of ½-inch or ¾-inch plywood. The clock, which can be an old alarm clock, may be fastened to a slanted block of wood by a brass strap, or bolted to two upright pieces of ⅛-by-½-inch or similar sized brass stock. It must be mounted high enough so that the winding key is accessible. The rotating disk which supports the ruled paper chart should be made of thin sheet metal.

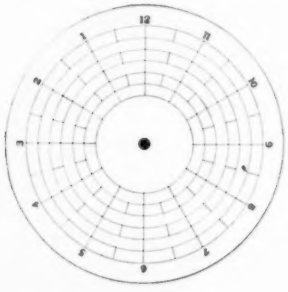
A small length of brass tubing is soldered to the hour-hand staff of the clock. Its diameter will depend upon the type of clock you use. In the outer end of this short piece of brass tubing is soldered a section of a brass bolt, with its head cut off. It will probably be 6-32 or 8-32 size. The disk and paper chart are mounted on this, using two nuts. The pie tin is mounted on two upright brass strips in the manner shown, and thumb screws, such as those which come on standard No. 6 dry-cell batteries, may be used for ease in removing the clockwork.

The clock, rotating disk and chart, and pie-tin cover are set on an angle so that rain, falling through the slit, will run off the chart and not spread around on it. All metal parts should have one or two coats of enamel or aluminum paint to prevent rust. If you care to, you may use more time lines than the hour and half-hour lines shown in the example. A good grade of bond paper should be used for the charts.

If you can obtain two small gears, of a 2-to-1 ratio, you may design this instrument so the chart will revolve once in 24 hours instead of 12. If no rain has fallen in a particular 12- or 24-hour period, let the chart continue to revolve until rain has been recorded.

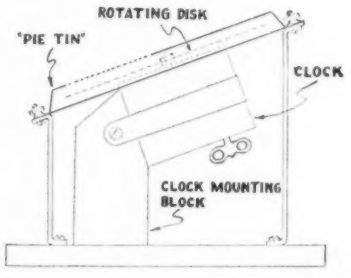


A phantom view of the ombroscope, showing the clockwork supported by two upright brass strips.



(Left) A sample of one of the recording charts, with half-hour divisions.

(Right) A side view of a model in which the clock is supported by a block to which it is clamped by a brass strip. Drawings and diagrams are by Charles A. Laird.



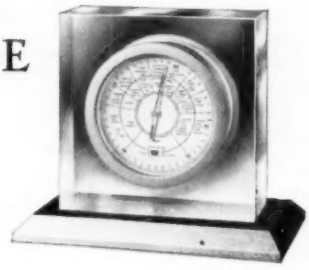
Style in Barometers

2410H

PENDANT BAROMETER

This beautiful instrument has an all-wood walnut frame and bezel. Its silver dial has Stormoguide face for indicating weather trends. Barometer movement is compensated for temperature and has an adjustment for altitude. The thermometer scale is mounted on a molded panel; the tube is filled with easy-reading red liquid. Barometer dial diameter is 6 inches; overall size is 31 by 9 inches. No. 2410H **$54.50**

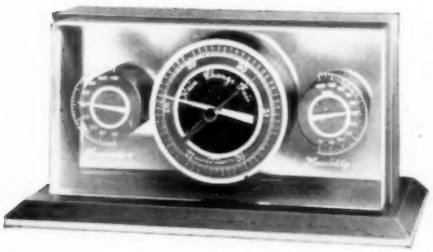
SOLITAIRE STORMOGUIDE



2596

This simplified weather forecaster, styled by Walter Dorwin Teague, is set in a solid block of crystal-clear plastic. The metal base is gold finished with trim to match. The signal device automatically indicates whether the barometer is rising or falling. The fine-quality movement has altitude adjustment for elevations from 0 to 3,500 feet. The instrument measures 7⅛ by 6¼ by 3¾ inches. No. 2596 ..... **$30.00**

COMBINATION BAROMETER



2592

Three weather instruments — barometer, hygrometer, thermometer — combined in one striking case styled by Walter Dorwin Teague. The crystal-clear plastic panels have frame and dials in gold finish, with figures and graduations in white lettering. An ideal gift for the modern home. Its open-center dial shows the fine temperature-compensated barometer movement. Altitude adjustment, 0 to 3,500 feet. The overall size is 12 by 6 by 4¼ inches. No. 2592 .... **$75.00**

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Two New Instruments

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These instruments employ tried and tested techniques developed by Bendix-Friez in its 73 years of manufacturing for science and industry.

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